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By
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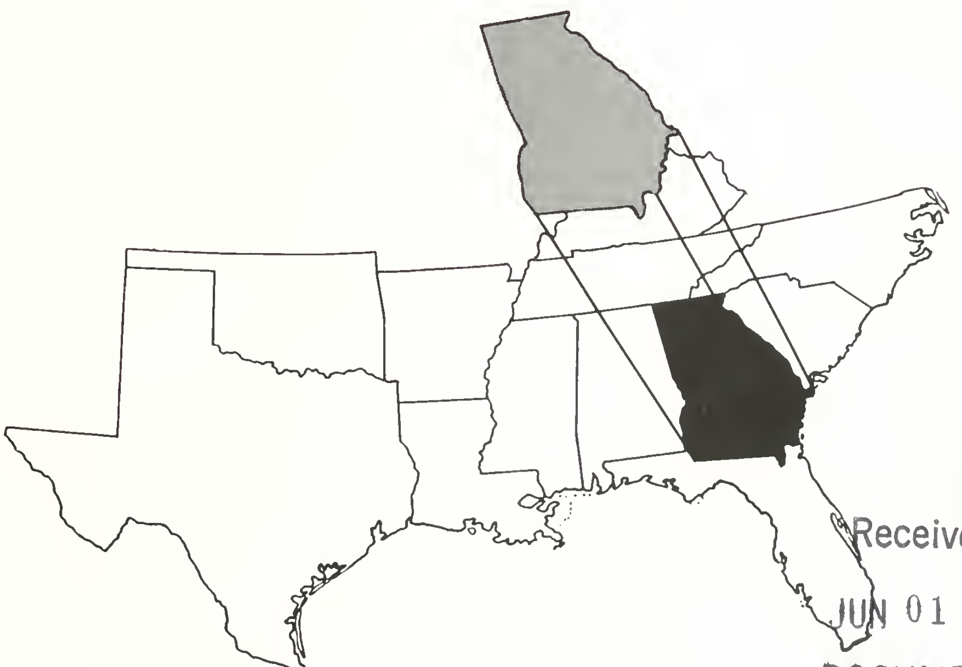

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ABSTRACT

Wind-pollinated slash pine progenies from (1) eight first-generation seed orchard clones, (2) bulked seed from their eight progenies in a 15-year-old seedling seed orchard, and (3) 15 individual second-generation selections from the progenies in the seedling seed orchard were tested on an Upper Coastal Plain and a flatwoods site in Georgia. Contrasts between progeny groups and checklots at age 5 years show that each selection stage beyond the unrogued cloanal seed orchard produced gain in resistance to fusiform rust. Variation within groups of first- and second-generation progenies remained high enough to afford further progress from selection, particularly in fusiform-rust resistance.

Genetic improvements in agricultural crops and domestic animals are greatly increasing profitability in agriculture and animal husbandry. The southern pines are being planted and grown as a crop, which presents both the opportunity and the need to apply genetic principles to increase profitability in forestry.

In the early 1950's Georgia Forestry Commission foresters located several hundred well-formed, fast-growing disease-free slash pines (*Pinus elliottii* Engelm. var. *elliottii*) as candidates for a tree improvement program. After further screening, 149 of these selected trees were propagated by grafting and used to establish two clonal seed orchards to supply seed needed for planting in Georgia.

Trees grown from these seeds are expected to be better in growth rate and other traits than trees from seeds collected in natural stands. But the only way to find out if they are better, and how much better, is to compare performance of their progeny with that of natural-stand check lots in properly designed studies. Questions about the potential for gain in succeeding generations of selection and breeding are: (1) How much genetic variation in economic traits is harbored in the selected genotypes? (2) How much gain can be made each generation? (3) Over how many generations of selection and breeding can successive gains be made?

As soon as ramets of the seed orchard clones began flowering, the Georgia Forestry Commission, in cooperation with the Southeastern Forest Experimetn Station, USDA Forest Service, began controlled pollinations to progeny test the clones. The first progeny tests, planted in 1961, included a plantation designed for conversion to a seedling-origin seed orchard. When the conversion was completed and the remaining seedling-origin seed orchard trees were flowering, a study was designed to quantify gains made in this second-generation orchard, to compare them with gains made in the first generation clonal orchard, and to compare performance of progenies from both orchards with that of natural-stand check lots.

Materials and Methods

The progenies included in the second-generation seedling seed orchard were from controlled pollinations of 17 of the clones in the first-generation clonal orchard. A mixture of pollen from 30 other clones in the orchard was used on these 17. The 17 "polymix" progenies produced were planted in a replicated design at the Georgia Forestry Commission's Arrowhead Seed Orchard in Pulaski County. Some 2,635 seedlings were planted. Roguing in 1967, 1969, 1971, and 1974 reduced the number to 141 trees, 5.35 percent of the original number. Trees removed were those (1) infected by the fusiform-rust fungus (*Cronartium quercuum* (Berk.) Miyabe ex Shirai f. sp. *fusiforme*), (2) with obviously slow growth, or (3) with poor stem or branch characteristics. In the 1974 roguing, spacing and flower production also were considered. One progeny that consistently grew slowly and had high fusiform-rust susceptibility was eliminated in 1974.

All cones were collected from the remaining seedling seed orchard trees in 1975 (about 4,000 cones) and 1976 (about 17,000 cones). Each year, the seeds were kept separate by individual tree. A bulk lot representing the rogued seedling seed orchard was made in each of the two years by mixing seed from each tree in proportion to that tree's contribution to total orchard yield. These two bulk lots were overall orchard check lots. In addition, eight family bulk lots were made from the 1976 collection. The three kinds of seed lots available from the seedling seed orchard, therefore, were two overall bulk lots, eight family bulk lots, and individual-tree lots, all from wind-pollinated seeds.

The maternal parents of the eight seedling orchard families from which the bulk seed lots were made are still in the rogued first-generation clonal orchard. Wind-pollinated seeds were collected from these eight clones for use in the study. Both seed orchards are surrounded by a large area of loblolly pine-hardwood forest and farm land, so outside slash pine pollen is at a very low level.

Two other check lots were obtained from the Georgia Crop Improvement Association. One was commercial seed from Telfair, Treutlen and Emanuel Counties, and the other a bulk lot from the unrogued first-generation clonal orchard. Both were collected in 1965.

Four kinds of seed lots were included in the study:

(1) wind-pollinated seeds from eight of the clones remaining in the rogued first-generation orchard;

(2) family-bulk lots from second-generation polymix progenies of the eight clones in (1), which were in a rogued seedling seed orchard;

(3) individual-tree lots from 15 second-generation trees selected from 6 of the progenies in (2); and

(4) four check lots -- two bulk lots from the seedling seed orchard, one bulk lot from the unrogued clonal orchard, and a commercial collection. The total number of seedlots was 35 (Appendix table 1).

Seedlings for the study were grown in 1978 by the Georgia Forestry Commission in the Morgan Nursery near Byron, GA., and planted as 1-0 stock in the spring of 1979 on two test sites in Georgia. One was a flatwoods site in Ware County and the other an Upper Coastal Plain site in Houston County. At both locations each seed lot was replicated five times in 16-tree plots in a randomized complete block design. Spacing was 2.5m x 2.5m (8.2' x 8.2') in Houston County and 2.5m in bedded rows approximately 3.7m (12') apart in Ware County.

At ages 2, 3, and 5 years, survival, height, and fusiform-rust infection were measured or assessed at both test sites. Only the fifth-year results are reported here, but the fifth-year rust data reflect all mortality from rust through age 5. Rust infection was expressed as the number of cankers per seedling and as the percentage of seedlings free of rust at age 5. Prior to analysis of variance, percentages were transformed to arcsins of their square roots. Means were separated with Duncan's multiple range test (Duncan 1955). Data were analyzed for each of the two planting sites and for the two sites combined.

The various check lots and family and progeny groups in this study represent stages of selection ranging from unselected natural stands to progenies from second-generation selections. Six contrasts between means of these groups were contstructed and tested for significance. Also, the relative variation remaining among families within groups (1), (2), and (3) above was determined.

RESULTS AND DISCUSSION

Trait means for the groups representing the various stages of selection, along with six contrasts and their significance tests, are shown in Table 1. The numbers assigned to the seedlots in Table 1 represent the various stages of selection and breeding, and the contrasts were designed to show gains made in individual stages. Only one contrast was significant on the flatwoods site but five were for the fusiform-rust and one for the height traits on

the Upper Coastal Plain site. All the significant contrasts selection stage produced an increment of gain rather than involved changes in the desired direction; that is, that loss. For cankers per tree, negative contrasts reflect the desired change, whereas positive contrasts are desired for the other traits.

For the fusiform-rust traits, the only contrast showing an undesirable response to selection was that between the unrogued clonal orchard check and the commercial check (2 vs 1, Table 1). The unrogued orchard check was more susceptible than the commercial check on both sites, though not significantly so. Apparently, selecting rust-free trees in natural stands did little to increase the proportion of rust resistance genes in the unrogued clonal orchard relative to that in natural stands. Later roguing and selection based on progeny test results have been effective in increasing rust resistance.

Along with the increase in rust resistance has come little change in survival and only moderate improvement in height growth rate. However, selection after the initial stage has been primarily for rust resistance, so this result is not surprising. Selection for survival *per se* was not performed so the only survival response to be expected would be one that is correlated with a trait that was selected for, such as rust resistance. Such a correlated response in survival may appear as the trees get older and more rust mortality occurs.

Contrasts between groups 1 (commercial check) and 6 (progenies from second generation selections) (Table 1) give estimates of total gains after two generations of selection. On the Upper Coastal Plain site, gain in the rust-free trait was 15.7 percentage points, or 53.6 percent of the check. The decrease in number of cankers per tree was 13.7 percent of the check. Also realized was an 11.1

Table 1.--Group means and contrasts between groups for fusiform-rust, height, and survival at age 5 years of slash pine tested on two sites.

Group and Contrast	Trait: Rust-free	Cankers/tree	Height	Survival
Upper Coastal Plain Site				
1. Commercial check	29.3	4.38	3.23	80.0
2. Clonal orchard check	20.4	5.03	3.60	82.5
3. First-generation families	32.8	4.47	3.55	78.0
4. Seedling S.O. bulk (1976)	59.2	2.56	3.76	88.4
5. Second-generation bulk families	42.6	3.22	3.56	77.9
6. Second-generation selections	45.0	3.78	3.59	80.5
2 vs 1	- 8.9	0.65	0.37	2.5
3 vs 2	12.4	-0.56	-0.05	-4.5
4 vs 3	26.4	-1.91*	0.21**	10.4
5 vs 3	9.8**	-1.25*	0.01	-0.1
5+6 mean vs 3	11.0*	-0.97**	0.02	1.2
6 vs 5	2.4	0.56	0.03	2.6
Flatwoods Site				
1. Commerical check	94.4	0.10	2.34	62.5
2. Clonal orchard check	86.0	.66	2.13	46.2
3. First-generation families	90.0	.12	2.41	55.4
4. Seedling S.O. bulk (1976)	100.0	.00	2.16	46.2
5. Second-generation bulk families	91.8	.10	2.41	53.7
6. Second-generation selections	92.5	.10	2.39	58.9
2 vs 1	-8.4	0.56	-0.21	-16.3
3 vs 2	4.0	-0.54*	0.28	9.2
4 vs 3	10.0	-0.12	-0.25	-9.2
5 vs 3	1.8	-0.02	0.00	-1.7
5+6 mean vs 3	2.1	-0.02	-0.01	0.9
6 vs 5	0.7	0.00	-0.02	5.2

** Significant at the 0.01 level.
* Significant at the 0.05 level.

percent gain in height. In the plantation on the flatwoods site, the only gain was 2.1 percent of the check in height.

Considerable variation in rust resistance still exists among first- and second generation families and among second-generation selections (table 2). Further gains should be possible with further selection and testing, especially in the plantation on the Upper Coastal Plain site where rust incidence has been quite high. Since very low rates of infection have occurred on the flatwoods site (Appendix tables 2-5), little opportunity for selection for rust resistance is expected in that plantation.

Table 2.--The standard deviation among families within groups expressed as a percentage of the mean of the group for four traits at age 5 years.

Family	Trait	Plantation site: Upper Coastal Plain	Plantation site: Flatwoods
		----percent----	
Families of first-generation clones	Rust-free	36.8	77.8
	Cankers/tree	41.0	7.3
	Height	9.0	12.2
	Survival	7.8	32.4
Second-generation bulk families	Rust-free	23.0	166.7
	Cankers/tree	33.0	13.8
	Height	4.8	27.1
	Survival	6.7	35.8
Families from second-generation selections	Rust-free	52.2	121.9
	Cankers/tree	60.2	9.2
	Height	7.8	24.7
	Survival	9.1	52.5

LITERATURE CITED

Duncan, D B. 1955. Multiple range and multiple *F* tests. Biometrics 11:1-42.

Appendix table 1.--Description of progenies and check lots of slash pine.

Progeny or Check	Description
60[1/]XW	60 x wind (5-ramet mix) - First-generation family
(60XP)XW,B	(60 x polymix) x wind (15-tree mix) - Second-generation bulk
(60XP)XW,S	(60 x polymix) x wind - Second-generation selection
(60XP)XW,S	(60 x polymix) x wind - Second-generation selection
(60XP)XW,S	(60 x polymix) x wind - Second-generation selection
(60XP)XW,S	(60 x polymix) x wind - Second-generation selection
119XW	119 x wind (5-ramet mix) - First-generation family
(119XP)XW,B	(119 x polymix) x wind (5-tree mix) - Second-generation bulk
(119XP)XW,S	(119 x polymix) x wind - Second-generation selection
(119XP)XW,S	(119 x polymix) x wind - Second-generation selection
(119XP)XW,S	(119 x polymix) x wind - Second-generation selection
94xW	94 x wind (2-ramet mix) - First-generation family
(94XP)XW,B	(94 x polymix) x wind (6-tree mix) - Second-generation bulk
(94XP)XW,S	(94 x polymix) x wind - Second-generation selection
(94XP)XW,S	(94 x polymix) x wind - Second-generation selection
(94XP)XW,S	(94 x polymix) x wind - Second-generation selection
50XW	50 x wind (4-ramet mix) - First-generation family
(50XP)XW,B	(50 x polymix) x wind (6-tree mix) - Second-generation bulk
(50XP)XW,S	(50 x polymix) x wind - Second-generation selection
(50XP)XW,S	(50 x polymix) x wind - Second-generation selection
20XW	20 x wind (5-ramet mix) - First-generation family
(20XP)XW,B	(20 x polymix) x wind (3-tree mix) - Second-generation bulk
(20XP)XW,S	(20 x polymix) x wind - Second-generation selection
(20XP)XW,S	(20 x polymix) x wind - Second-generation selection
71XW	71 x wind (3-ramet mix) - First-generation family
(71XP)XW,B	(71 x polymix) x wind (3-tree mix) - Second-generation bulk
(71XP)XW,S	(71 x polymix) x wind - Second-generation selection
6XW	6 x wind (5-ramet mix) - First-generation family
(6XP)XW,B	(6 x polymix) x wind (4-tree mix) - Second-generation bulk
76XW	76 x wind (4-ramet mix) - First-generation family
(76XP)XW,B	(76 x polymix) x wind (4-tree mix) - Second-generation bulk
Check 1	Seedling seed orchard bulk - 1975
Check 2	Seedling seed orchard bulk - 1976
Check 3	Commercial seed collection (Georgia Crop Improvement Assoc.)
Check 4	Seed orchard collection (Georgia Crop Improvement Assoc.)

1/ Georgia Forestry Commission serial numbers for the first-generation selections.

Appendix table 2.--Significance tests for the various sources of variation in four traits at age 5 years in two slash pine test plantings analyzed separately and combined.

Source of variation	Trait			
	Rust-free	Cankers/tree	Height	Survival
Upper Coastal Plain Site				
Replication		**	**	**
Seed lot (all)	**	**		
First-generation families		*		
Second-generation families				
Second-generation selections	**	**		
Flatwoods Site				
Replication	**	**		**
Seed lot (all)			*	*
First-generation families	*	*		
Second-generation families			*	
Second-generation selections			*	*
Two sites combined				
Site	**	**	**	**
Replication in site	**	**	**	**
Seed lot (all)	**	**	*	**
First-generation families	**	*		*
Second-generation families	**			
Second-generation selections	**	**	*	*
Site x seed lot		**		

** Significant at the 0.01 level
 * Significant at the 0.05 level

Appendix table 3.--Means for rust, height and survival traits at age 5 years for wind-pollinated families from first generation orchard clones of slash pine tested on two sites[1/]

Family	Trait			
	Rust-free	Cankers/tree	Height	Survival
	Percent	Number	m	Percent
		Upper Coastal Plain Site		
60XW	54.2a	2.00a	3.91a	78.8a
6XW	41.2ab	5.50ab	3.62ab	75.0a
50XW	39.7ab	4.44ab	3.45b	79.9a
119XW	33.8ab	5.58ab	3.46b	75.0a
76XW	27.3ab	4.22ab	3.51b	81.1a
94XW	26.4ab	3.18ab	3.38b	80.0a
71XW	25.8ab	3.80ab	3.53b	78.1a
20XW	14.2b	7.02b	3.54b	76.0a
Mean	32.8	4.47	3.55	78.0
		Flatwoods Site		
60XW	98.6a	0.02a	2.46a	56.2a
76XW	92.7a	.07a	2.45a	63.5a
94XW	92.3a	.09a	2.30a	71.2a
20XW	89.6a	.16a	2.54a	44.4a
6XW	89.3a	.14a	2.26a	56.2a
50XW	88.1a	.18a	2.26a	34.6a
119XW	88.0a	.14a	2.62a	61.2a
71XW	84.3a	.16a	2.37a	56.2a
Mean	90.3	0.12	2.41	55.4

1/ Means followed by a common letter do not differ significantly at the 0.05 level, according to Duncan's Multiple range test.

Appendix table 4.--Means for rust, height and survival traits at age 5 years for second-generation bulk families of slash pine tested on two sites[1/].

Family	Trait			
	Rust-free	Cankers/tree	Height	Survival
	Percent	Number	m	Percent
		Upper Coastal Plain Site		
(60XP)XW,B	51.6a	2.92a	3.63a	77.5a
(71XP)XW,B	50.4a	2.74a	3.58a	81.2a
(20XP)XW,B	49.5a	2.51a	3.62a	77.5a
(6XP)XW,B	46.4a	2.11a	3.63a	78.7a
(76XP)XW,B	40.8a	3.54a	3.54a	81.2a
(119XP)XW,B	36.2a	3.10a	3.61a	82.5a
(50XP)XW,B	35.3a	2.42a	3.44a	78.1a
(94XP)XW,B	30.4a	6.44b	3.40a	66.2a
Mean	42.6	3.22	3.56	77.9
		Flatwoods Site		
(50XP)XW,B	98.7a	0.01a	2.19b	38.5a
(71XP)XW,B	95.6a	.04a	2.35b	57.5a
(119XP)XW,B	95.3a	.05a	2.09b	42.5a
(60XP)XW,B	95.0a	.05a	2.35b	42.5a
(20XP)XW,B	94.6a	.05a	2.40b	48.8a
(6XP)XW,B	93.5ab	.08ab	3.01a	69.5a
(94XP)XW,B	85.1bc	.21bc	2.62ab	68.8a
(76XP)XW,B	76.9c	.29c	2.28b	61.2a
Mean	91.8	.10	2.41	53.7

1/ Means followed by a common letter do not differ at the 0.05 level, according to Duncan's Multiple range test.

Appendix table 5.--Means for rust, height and survival traits at age 5 years for progenies from the second-generation selections of slash pine tested on two sites [1/]

Family	Trait: Rust-free	Cankers/tree	Height	Survival
	Percent	Number	m	Percent
		Upper Coastal Plain Site		
(60XP)XW,S	74.8a	1.52ab	3.55a	77.5a
(71XP)XW,S	70.1ab	1.26ab	3.65a	96.5a
(60XP)XW,S	68.1a-c	1.25a	3.65a	78.7a
(119XP)XW,S	64.6a-d	1.29ab	3.51a	82.5a
(20XP)XW,S	52.5a-e	4.69a-d	3.67a	82.5a
(60XP)XW,S	48.5b-f	2.54a-c	3.73a	75.4a
(50XP)XW,S	48.5c-g	2.36a-c	3.43a	79.2a
(94XP)XW,S	44.2d-g	4.92a-d	3.30a	86.2a
(20XP)XW,S	42.4d-g	3.75a-d	3.68a	76.2a
(119XP)XW,S	36.3e-g	7.86d	3.76a	75.0a
(94XP)XW,S	31.3e-g	6.16cd	3.46a	80.0a
(119XP)XW,S	27.9e-g	4.99b-d	3.69a	81.4a
(60XP)XW,S	26.5fg	7.88d	3.69a	81.2a
(94XP)XW,S	25.0gh	2.97a-d	3.66a	74.9a
(50XP)XW,S	17.5h	3.23a-d	3.44a	80.0a
Mean	45.0	3.78	3.59	80.5
		Flatwoods Site		
(60XP)XW,S	100.00a	0.00a	3.06a	69.6a
(20XP)XW,S	98.2a	.04a	2.12bc	37.5b
(60XP)XW,S	97.8a	.04a	2.42bc	71.2a
(71XP)XW,S	96.4a	.04a	2.05c	58.6ab
(50XP)XW,S	94.4a	.06a	2.26bc	39.6b
(20XP)XW,S	94.1a	.10a	2.28bc	52.5ab
(119XP)XW,S	94.0a	.14a	2.15bc	48.8ab
(60XP)XW,S	93.3a	.13a	2.63a-c	72.3a
(94XP)XW,S	92.3a	.09a	2.24bc	56.2ab
(60XP)XW,S	91.5a	.09a	2.73ab	56.2ab
(50XP)XW,S	90.0a	.10a	2.19bc	32.9b
(119XP)XW,S	88.8a	.16a	2.41bc	52.3ab
(119XP)XW,S	88.6a	.11a	2.37bc	58.8ab
(94XP)XW,S	85.6a	.14a	2.54ac	61.5ab
(94XP)XW,S	82.7a	.30a	2.38bc	40.0b
Mean	92.5	.10	2.39	58.9

1/ Means followed by a common letter do not differ at the 0.05 level, according to Duncan's Multiple range test.

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